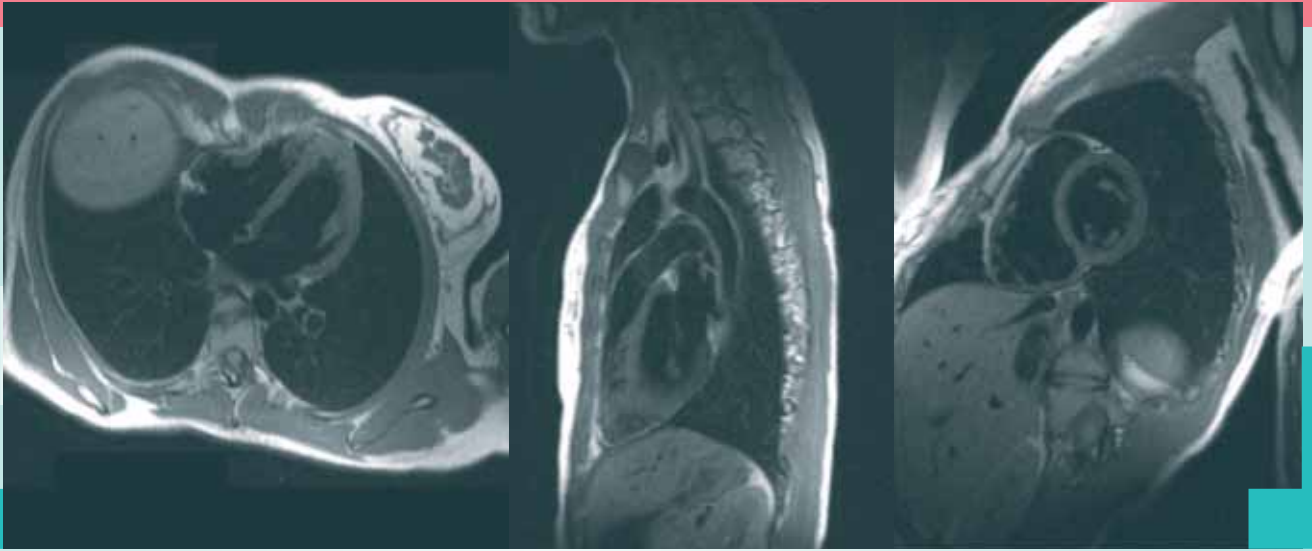


# Magnetic resonance imaging

Imaging scanners that detect signals from magnetic nuclei in living tissues are revolutionising biomedical knowledge and opening the way to earlier diagnosis and safer, less invasive surgery



Images of the heart taken in different planes



## A powerful imaging tool for medicine



MRI pioneer Sir Peter Mansfield of the University of Nottingham

**M**any people today will have had a magnetic resonance imaging (MRI) scan to diagnose a medical condition. In the past 20 years, MRI has evolved from an ingenious idea into a routine method for looking at structures inside the body. As instrumentation and methods of acquiring the image continue to improve, new remarkable applications are still emerging, making MRI one of the most significant technologies for improving human health.

The development of MRI is an extraordinary story in that it emerged in the field of esoteric nuclear physics – clearly illustrating the benefits of fundamental research to everyday life. Seventy years ago, physicists explored how atomic nuclei with magnetic moments, when aligned by an external magnetic field, absorbed pulses of radio waves. The nuclei twist out of alignment at particular radio frequencies (the resonant frequency), and then re-emit the energy as they 'relax' back to their original state. The signal detected depends not only on the type of

nucleus and magnetic field strength but also on its physical and chemical environment – for example, the molecular structure in which the host atom sits. Any molecule containing magnetic nuclei, such as those of hydrogen (single protons), therefore produces a characteristic spectrum of nuclear magnetic resonance (NMR) frequencies when subjected to a magnetic field and a radio-frequency (RF) pulse; NMR spectroscopy is now one of the most important ways of analysing chemical structure, particularly of organic and bio-molecules.

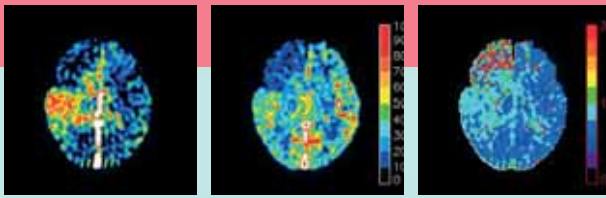
Physicists also noted that the water (which contains two single protons in hydrogen atoms) in biological tissues gave an NMR signal that relates to its distribution and environment. This suggested that living structures such as blood vessels and muscles could be imaged by scanning the water content across an organ. In the 1970s, the American scientist Paul Lauterbur and the Nottingham-based physicist Peter Mansfield (now Sir Peter) thought of using additional field gradients in different directions to distinguish the spatial position of nuclei. The signal obtained could be broken

down into its basic components using complex mathematical methods and then processed to create a three-dimensional image. The first coarse images took a long time to acquire, but gradually more rapid methods of imaging were proposed, and now they can be obtained in less than a second. Lauterbur and Mansfield are among several scientists who have won Nobel Prizes for breakthroughs in the field of NMR.

By the 1980s, instruments that could image inside a patient were being built for clinical use, and in this context the name of the technique was changed to the more reassuring 'magnetic resonance imaging'. Today, there are about 20,000 MRI scanners worldwide, with more than 70 million scans performed every year. Typically, they employ a powerful magnet with a field strength of about 1.5 tesla (20,000 times the Earth's magnetic field). The patient lies in a channel along the central axis of the magnet. Unlike CAT scans, the procedure produces no harmful side-effects, and can image soft tissues that are transparent to X-rays. The images are three-dimensional,

A typical MRI scanner





MRI scans showing changes in blood flow in the brain due to a stroke

and the latest MR systems offer resolutions down to the submillimetre-scale.

The technique has benefited enormously from collaborations between physicists and clinicians. For example, doctors can see more if the image 'contrast' is improved. This can be done by manipulating the RF pulses and magnetic fields so as to spread out the time taken for nuclei in different tissues to relax back to their initial state. Or chemical contrast agents may be injected to highlight target structures. Another new possibility is to introduce MR-sensitive molecules that bind to specific receptors in the target tissue.

### What MRI can do

MRI distinguishes between normal and diseased tissue through differences in water content and how it is bound chemically. It is particularly effective for diagnosing tumours and other abnormalities in the brain. The technique can also image blood flow in arteries and through the heart, as well as muscle and bone injuries.

Applications continue to advance rapidly, and UK research groups at many of the major hospitals are at the forefront of developments. One growing area is to use MRI to study physiological changes in real time. For example, scientists at Nottingham are trying to understand appetite by following what happens to fatty food in the stomach, and also by monitoring how the brain responds to taste. They have also studied the brain activity of the unborn child in response to various stimuli.

Another approach is to look at chemical changes in brain metabolism directly using

spectroscopic signals from molecules of interest – for example, glucose labelled with carbon-13 (which has a magnetic moment). Signals from other elements such as sodium could also be used to follow neurological changes. Helium gas, prepared in a highly polarised (aligned) state, can be employed to image lungs, which contain little water.

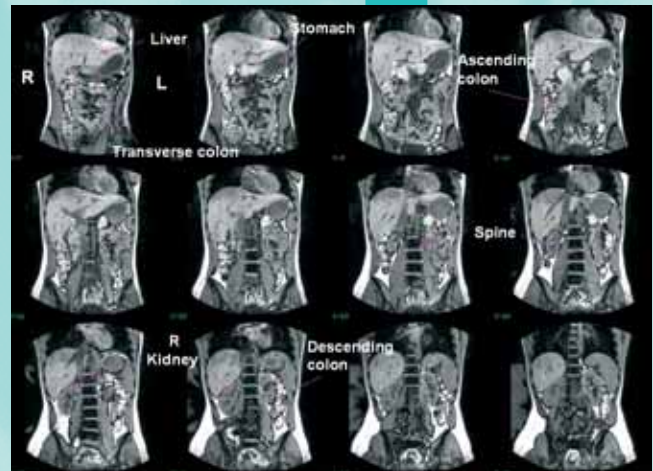
The area that most excites researchers is the application of MRI in surgery. This is a new field but it is developing fast. At the moment, several London hospitals are employing MRI as a planning tool, to aid, for example, breast and prostate biopsies. A team at Guy's Hospital is pioneering MRI in cardiac intervention surgery. Although X-rays are used to guide a catheter into the heart, say, to insert a device to seal a defect, MRI is able to monitor the success of the procedure by providing a detailed image of the heart before and after the intervention.

In the case of children needing several operations, the accumulated X-ray dose may significantly increase the risk of cancer. So the eventual aim is to rely solely on MRI to guide surgery, particularly on the heart

and brain. However, the equipment is expensive and the approach is currently limited by the fact that metal instruments cannot be used (as their intrinsic magnetism distorts the image); MRI-compatible surgical implements still need to be developed. MRI is also very noisy.

Technological developments that will enhance MRI are coming along, including smaller and more open scanners. New methods of collecting data using arrays of RF detectors are being developed, as are computational techniques that select only the data of interest. These developments will improve patient comfort as well as speed up image-acquisition and improve resolution. We can look forward to an exciting future for MRI.

The abdominal cavity and digestive system as seen with a 1.5-tesla scanner



## SOME MRI APPLICATIONS

### Diagnosis of:

- Tumours
- Multiple sclerosis
- Strokes
- Parkinson's disease
- Schizophrenia
- Coronary heart disease
- Congenital heart problems
- Torn ligaments and slipped discs
- Foetal development

### In surgery to:

- Plan surgical procedures
- Guide and monitor operations

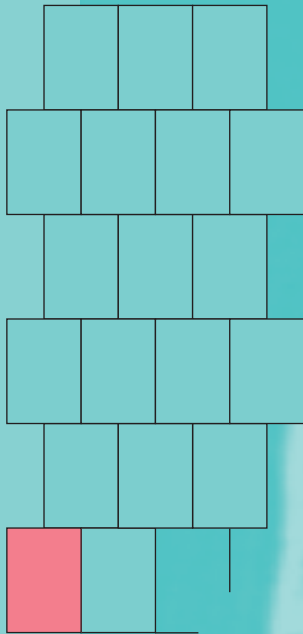
### Medical and biochemical studies of:

- Physiological processes
- Brain activity and cognitive neuroscience
- Body biochemistry
- Drug metabolism

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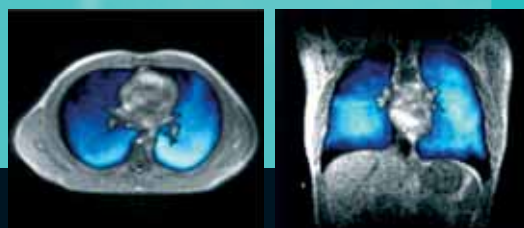
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Further information on MRI can be found on the following websites:

<http://electronics.howstuffworks.com/mri.htm>  
[http://en.wikipedia.org/wiki/Magnetic\\_resonance\\_imaging](http://en.wikipedia.org/wiki/Magnetic_resonance_imaging)  
[www.magres.nottingham.ac.uk](http://www.magres.nottingham.ac.uk)



MR images of lungs using hyperpolarised helium-3

Front cover:  
A high resolution image of the brain taken with Nottingham's new 7-tesla 'Ultra High Field Magnetic Resonance Facility'

Inset:  
The world's first MR images of catheter manipulation during a heart operation. They were taken at a rate of 10 images per second

Below left:  
MR images of lungs using hyperpolarised helium-3

Credits:  
Brain, abdominal and lung images supplied by the Sir Peter Mansfield Resonance Centre, University of Nottingham. Cardiac images are from Guy's Hospital, King's College London.